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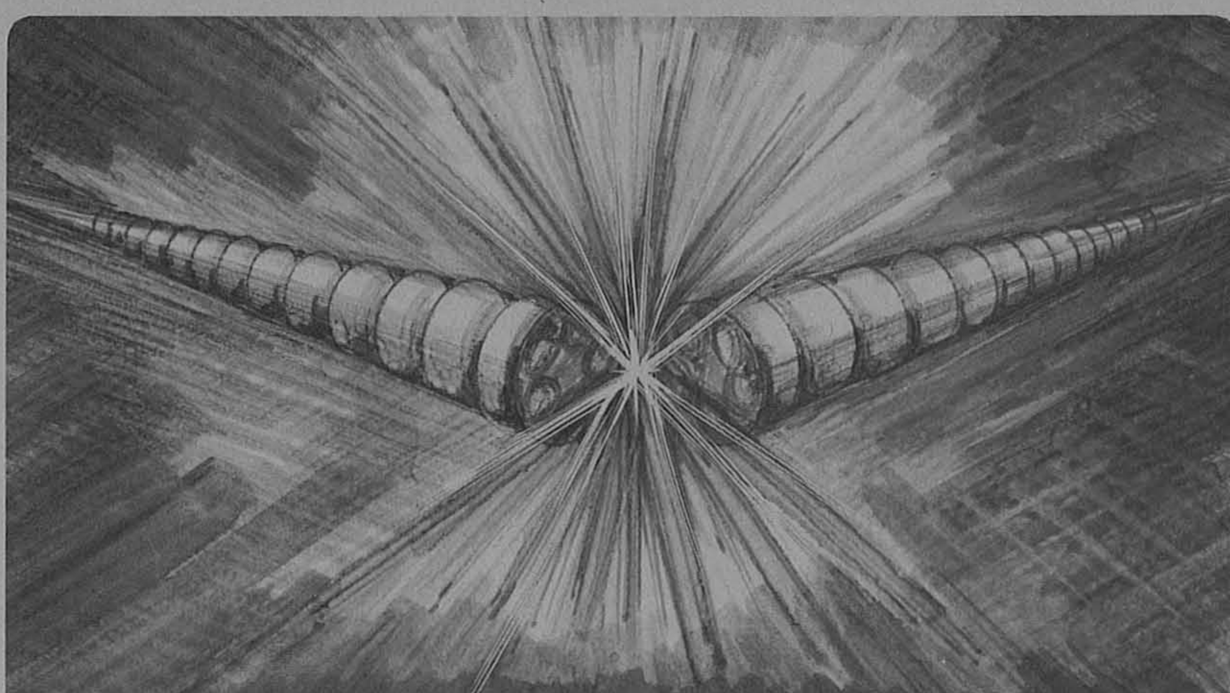

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BEAM-BEAM INTERACTION IN AN ASYMMETRIC COLLIDER FOR B-PHYSICS*

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Abstract This note is devoted to deriving the minimum criteria to achieve a symmetrical behavior of unequal energy beams in asymmetric colliders for B-physics. The computer simulation results suggest that at least the following quantities should be equalized in the two rings: beam-beam tune shift, cross-sectional area at the interaction point, damping decrement per turn, and betatron phase modulation due to synchrotron motion.

INTRODUCTION

An asymmetric collider with unequal beam energies has been discussed recently as an interesting possibility to measure CP violation asymmetries in B-meson decay.[1] In such a design, the two rings may have totally different parameters. As is true for the symmetric collider case, a major limitation on the attainable luminosity is expected to come from the beam-beam interaction. However, the beam-beam situation is much more complicated in asymmetric colliders: two beams with unequal energies tend naturally to behave differently. Indeed, what is often observed in computer simulations is that one beam blows up badly, while the other beam suffers practically no blowup. This is a serious problem, since the significant blowup in the weaker beam imposes a very low beam-beam tune shift limit on the stronger beam. Probably, the best cure is to bring the beam-beam interaction into the "strong-strong" regime, where the two beams blow up in a similar manner, reducing the beam-beam force on both beams simultaneously. In this way, we might expect to reach the same maximum beam-beam tune shift limit attainable in a symmetric collider.

In this note, we try to derive the minimum criteria necessary to satisfy the above "asymmetric energy transparency" condition by applying a modified version of Yokoya's simulation program to APIARY-I.[2] Recently, Siemann[3] has pointed out that the betatron

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phase advance during the collision may give non-negligible effects in beam blowup when the beta function, β^*, at the interaction point (IP) gets comparable to the bunch length. He concluded that it is necessary to treat the beam-beam interaction as a thick element. This thick lens approximation is accomplished in Yokoya's program by distributing beam-beam kicks into five longitudinally different positions and letting particles drift between them. The rms beam sizes of the incoming beams are assumed to be unchanged during the collision in this approximation.

PRIMARY RESULTS

The main parameters of the original APIARY-I lattice are shown in Table I.

Table I. Main parameters of the original APIARY-I lattice

	Low energy ring	High energy ring
Energy, E (GeV)	2	12
Circumference, C (m)	155.3	2200
Number of bunches, k_B	6	81
Emittance, ε_x (m·rad)	3×10^{-7}	1×10^{-7}
Bunch length, σ_s (mm)	27.74	16.22
Transverse damping time, $\tau_{x,y}$ (ms)	16.33	15.6
Beta function at IP, β_x^* (m)	0.254	0.762
β_y^* (m)	0.0254	0.0762
Bunch current, I_b (mA)	89.08	3.26
Nominal beam-beam tune shift, ξ_{ox}	0.05	0.05
ξ_{oy}	0.05	0.05
Luminosity, L ($cm^{-2}sec^{-1}$)	5×10^{32}	

These parameters provide

Criterion 1: same cross-sectional area at IP

$$\sigma_{\ell x} = \sigma_{hx}$$
$$\sigma_{\ell y} = \sigma_{hy}$$

Criterion 2: same nominal beam-beam tune shift

$$\xi_{o\ell x} = \xi_{o\ell y} = \xi_{ohx} = \xi_{ohy} \ ,$$

where the quantities of the low and the high energy rings are denoted by the subscripts ℓ and h, respectively.

With these parameters, the beam-beam kicks are equalized in the two rings; any difference in beam dynamics should come from the difference of beam parameters elsewhere in the rings. The computer simulation results for this case are summarized in Figs. 1 and 2. Figure 1 shows the rms beam sizes as a function of the nominal beam-beam tune shift, ξ_o. One can see that the low energy beam blows up badly in the vertical plane, while the high energy beam is practically unperturbed. The actual luminosity at ξ_o = 0.05 drops by a factor of 5 from the design value. Figure 2 shows the dynamic beam-beam parameter, ξ, as a function of ξ_o. Reflecting the vertical blowup of the low energy beam, the tune shifts ξ_h of the high energy beam are suppressed to small values, e.g., ξ_{hy} is less than 0.008.

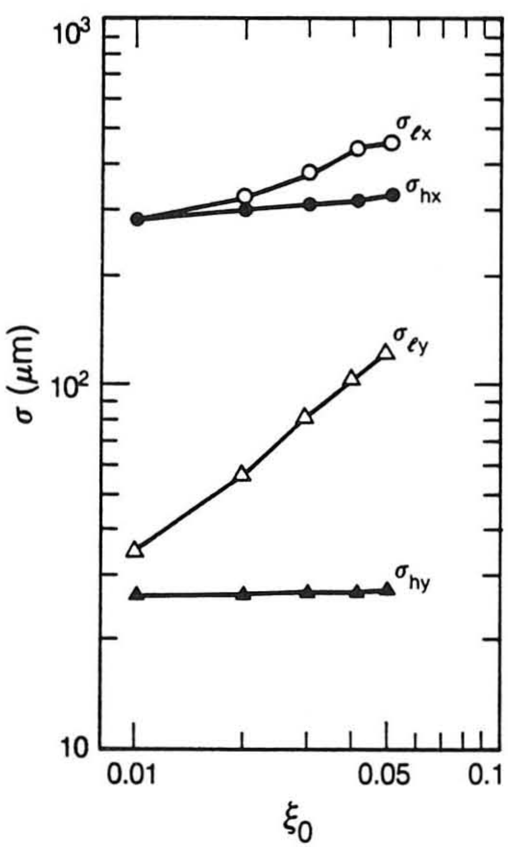

Fig. 1 RMS beam sizes predicted for nominal APIARY-I parameters

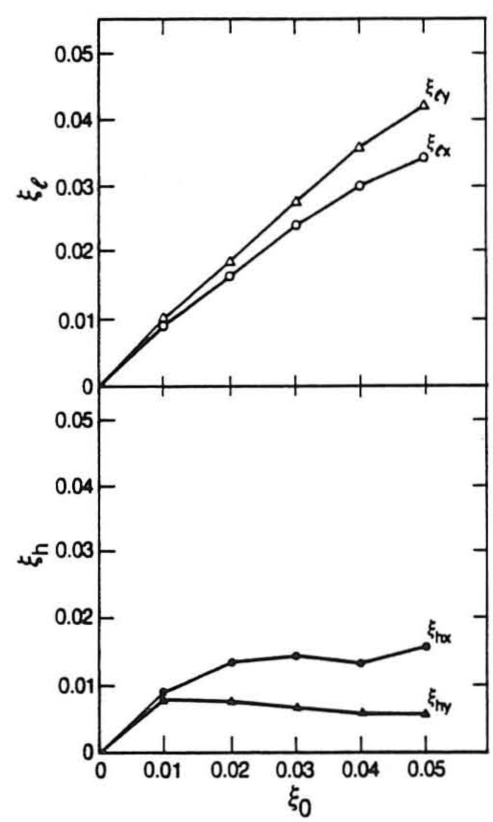

Fig. 2 Dynamic beam-beam parameters, ξ, as a function of ξ_o for the original APIARY-I lattice.

IN QUEST OF THE STRONG-STRONG SITUATION

Numerous simulations were subsequently made to achieve — by trail and error — identical behavior of two beams with unequal energies. Because we do not have enough space to describe all the attempts, we present here only the main results that lead to the asymmetric energy transparency condition.

Criterion 3: same damping decrement.

Synchrotron radiation damping is an important effect to suppress external perturbations to beams. There is some evidence[3,4] that shows that the larger the damping rate, the larger the beam-beam limit will be. From criterion 2, the strength of the beam-beam kick per turn is equal in the two rings. However, the number of kicks *per damping time* is different for the nominal APIARY-I parameters: the low energy beam receives about 14 times more kicks than the high energy one. Therefore, the low energy beam is subjected to the beam-beam interaction more, which may partially explain the asymmetric behavior of the two beams shown in Fig. 1. Figure 3 shows the rms beam sizes when the damping

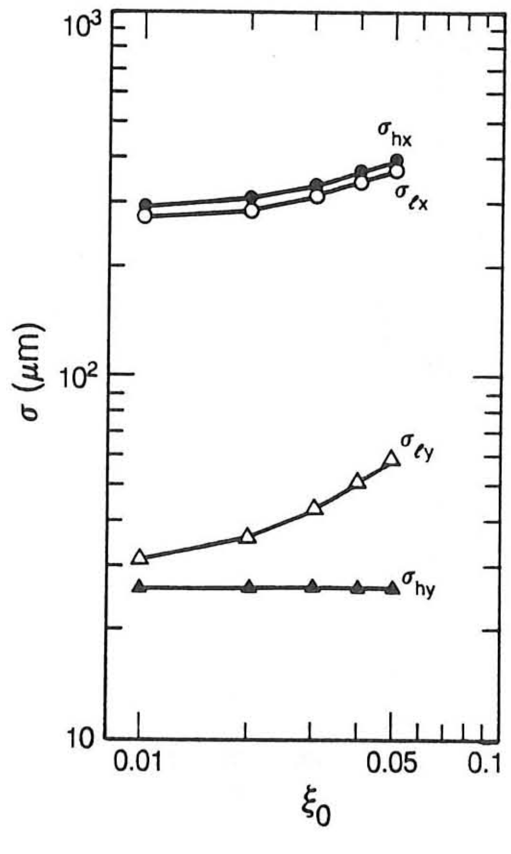

Fig. 3 RMS beam sizes when the two rings have the same damping decrement.

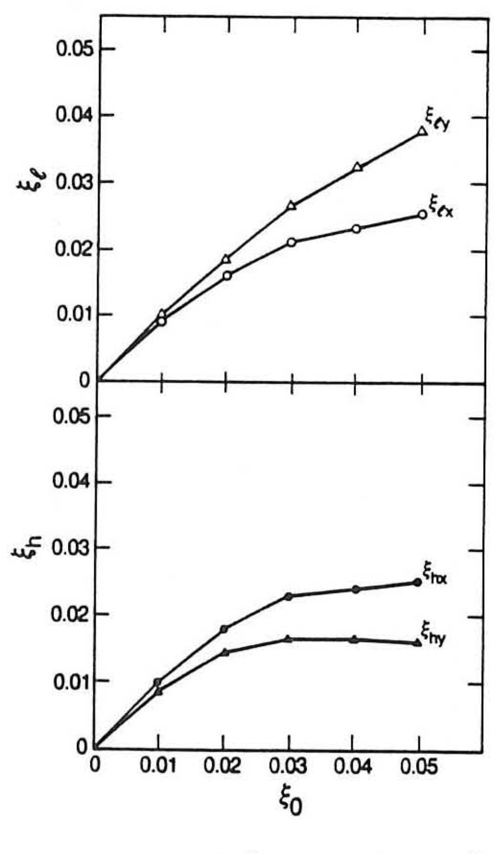

Fig. 4 Dynamic ξ as a function of ξ_0. The two rings have the same damping decrement.

decrement of the low energy beam is increased to the same value as the high energy one. Now, the vertical blowup of the low energy beam is reduced significantly compared with that in Fig. 1. The dynamic beam-beam parameters ξ_ℓ and ξ_h are plotted in Fig. 4 as a function of ξ_o. The horizontal ξ values behave almost identically, and the saturating value of ξ_{hy} is increased to ~0.017.

Criterion 4: same betatron phase modulation due to synchrotron motion (with possibly the same synchrotron tune).

The importance of this effect was demonstrated by the author. A particle with a longitudinal displacement, s, from the center of the beam collides with the center of the incoming beam not at the designed IP but at a position longitudinally shifted by s/2. This actual collision point moves turn by turn, because the particles execute synchrotron oscillations. Thus, the betatron phase advance per turn is also oscillating. This may excite synchro-betatron resonances, which may reduce the beam-beam limit substantially when β^* gets comparable to the bunch length σ_s. The amplitude of the tune modulation is given by[4] $(\sigma_s Q_s/\beta^*)$, where Q_s is the synchrotron tune. Figures 5 and 6 show the simulation results when the values of $(\sigma_s Q_s/\beta^*)$ are equalized in the two rings by adjusting σ_s and Q_s. The betatron tunes and Q_s are also set equal in the two rings. From Fig. 6, it can clearly be seen that the beam behavior has been almost equalized. Now, the beam-beam tune shift limit comes horizontally, but no saturation of ξ_x is observed.

CONCLUSIONS

We have shown that, under the four criteria given here, two beams of unequal energies should evolve in a similar manner dynamically. It may also be desirable to equalize other parameters, like the emittances and the beta functions at the IP, to ensure full overlap of the bunches in the interaction region. We note that if the synchrotron radiation takes place only in the normal bending magnets of the lattice, the same emittance cannot be compatible with the same damping decrement. A solution to this conflict, which is also desirable from the vacuum and beam lifetime points of view, is to use a "wiggler lattice" in which wigglers are distributed along the ring to produce and control the synchrotron radiation. At present, when there are no existing asymmetric colliders, it is not known how strictly the four criteria have to be satisfied, or how much they can be relaxed in real machines. Therefore, the wiggler lattice concept, which allows for extra flexibility in adjusting the lattice parameters, should be studied seriously.

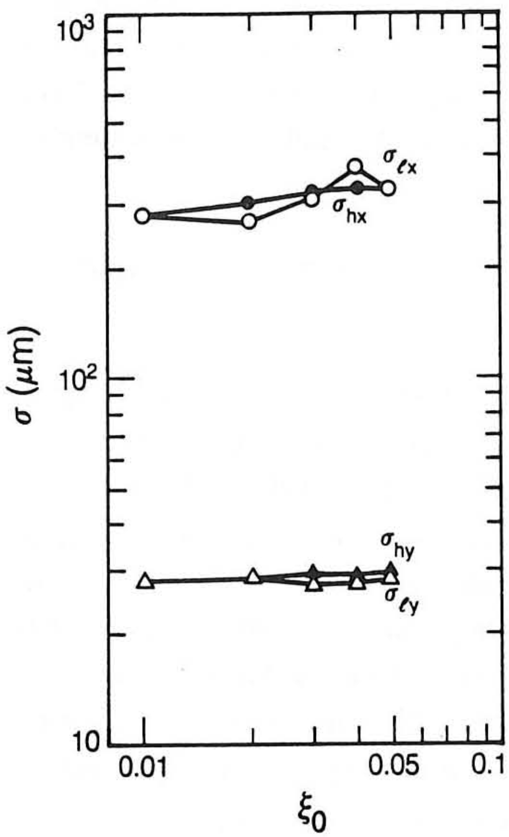

Fig. 5 RMS beam sizes when all four criteria are satisfied.

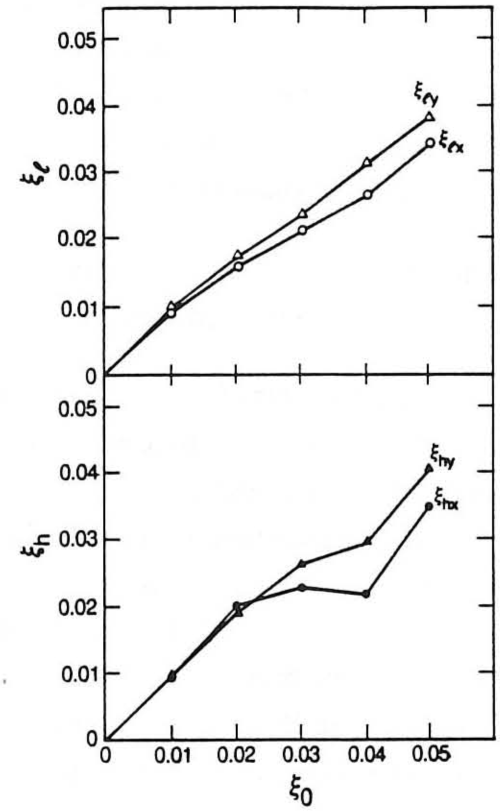

Fig. 6 Dynamic ξ as a function of ξ_0, when the two rings satisfy all the criteria 1-4.

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